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Preface

The four volumes that make up *History of Modern Science and Mathematics* have been organized with the aim of explaining to students at the high school and university level the central features of Western science within the context of its historical development. Although it is doubtless vital that these volumes impart to the student an informed and critical awareness of the scientific culture that has flourished in modern times and the prominent role that this culture has played in our understanding of the human condition and the place of humanity in the cosmos, we did not see it as our mission to provide a rationale for including these branches of knowledge in high school and university curricula. Indeed, we have taken it as axiomatic that mathematics and the sciences of nature are all worthy in their own right of being studied historically. Our mission, rather, was to furnish those who study and teach the history of science and mathematics with a set of pedagogical tools that would instill in the reader an appreciation of the richness and diversity of scientific practice.

Although it is true that, like other aspects of history, the history of science is made by individual persons and not by experimental devices and grand theories, we took the position early on in this project that science is more than the sum of the activities of heroic individuals—indeed, that the history of science is a rich network of thought and practice with many conduits and junctions. Individual scientists, of course, do make lasting contributions that often confer on their name an honorific status in the annals of science (e.g., the Copernican theory and the Faraday effect), but the enduring legacy of scientific endeavor is the rich network of disciplines that make up the science curriculum of schools, colleges, and universities. It is the historical development of these disciplines and their many interdisciplinary connections that is the subject matter of these volumes.

Because of the maturation of the history of science and mathematics as fields of academic study, these volumes have been enriched by the participation of professional historians from all over the globe. Authors of articles were requested to emphasize the scientific landmarks of their subject fields, striking, where appropriate, a balance in their narratives between the roles played by theory, experiment, technology, and calculation. The development of some branches of science (e.g., optics) has been driven by the spectacular rise of experimental technology to a greater extent than others (e.g., paleontology), and so this request was but an ideal that many of the articles could not realize.

These volumes face a nearly impossible task: Since the world of science is ever-changing, any reference book is bound to be dated within a few years of its publication. *History of Modern Science and Mathematics*, however, does not strive to bring the reader up to date with the most current cutting-edge innovations and developments. We aspired to create a collection of articles that would be authoritative in the sense that they would reflect the best historical scholarship, but for the most part, the scientific content is restricted to those areas of the science of nature and mathematics that are no longer progressive and changing and so are “historical objects of study” in the proper sense of this expression. Although the facts and theories reported in these pages are often out of step with the latest scientific opinion, these volumes do serve to instill in the reader a sense of the historical character of scientific knowledge and a critical sense of the social, cultural, and political context that helps to shape the approaches that scientists take to the study of nature.

A concerted effort has been made to make these volumes as comprehensive as a four-volume reference work can be. Even so, we have been compelled to be highly selective. There are far more scientists working in the latter half of the twentieth century than in all of previous history. Any attempt at history that recognizes and gives priority to this imbalance will give almost all its attention to recent decades. Although some of the articles explore the history of more recent scientific developments, in other articles such developments are discussed only in passing, if at all, in view of the fact that recent scholarship is very limited and, in some areas, such as contemporary work in the physics and chemistry of solids, virtually nonexistent. This limited availability of historical scholarship has shaped our editorial policy, so that the articles by and large are restricted to periods that are comparatively well traveled.

Most articles open in the seventeenth century, in the period immediately following the publication in 1543 of Copernicus's monumental *De revolutionibus orbium coelestium* (On the Revolutions of the Heavenly Spheres, 1543). The seventeenth century seemed an appropriate springboard for our endeavors: In addition to the rich and lofty body of mathematical theory that we associate with Isaac Newton's celebrated *Philosophiae naturalis principia mathematica* (Mathematical Principles of Natural Philosophy, 1687), the seventeenth century witnessed the creation of a scientific community with conditions of communication and education within which general agreement of basic aims, methods, and criteria of success could be reached. Since the creation of this community was deeply implicated in the specialization and differentiation of the various branches of the science of nature, it was decided that each article would open with seventeenth-century developments, following some preliminary discussion of the roots of these achievements in antiquity and the Middle Ages, where appropriate. Even this plan, however, called for exceptions. Atomic and nuclear science, for example, is a science of the late nineteenth and twentieth centuries. Although the atomic hypothesis dates back to Antiquity, the branch of science itself really emerged only at the turn of the twentieth century, so much of the article is given over to events that occurred between the 1890s and the 1930s.

The areas of science covered in *History of Modern Science and Mathematics* are those that in modern times fall under the rubric of mathematics and the sciences of nature. This includes astronomy, biology, chemistry, mathematics, physics, and subjects that fall under or are associated with these areas, such as developmental biology and genetics, meteorology and oceanography, and calculus and algebra. In addition, we have included articles on aspects of those social sciences (anthropology and psychology) that bear close ties to mathematics and the natural sciences.

Setting aside the topical essays and the overview articles that open the set, technology, medicine, and philosophy of science, as well as the social sciences, are included only in instances where some aspect of research was related intrinsically to the sciences of nature or to mathematics. The organizational decision not to include those branches of science that still carry the label "applied science"—agriculture, medicine, engineering, and the like—caused us the greatest amount of concern. After all, why shouldn't these applied sciences be included along with those branches that traditionally carry the label "pure science"? There are a number of reasons for resisting the distinction between pure and applied science and for including articles on medicine and the like. Most compellingly, historical research has shown conclusively that the distinction between pure and applied science is misleading because it sustains the age-old conviction that pure science precedes applied science and that the practical attempt to apply the theoretical results of science in concrete situations is a secondary and inferior kind of endeavor. Study after historical study has revealed that, as often as not, it is a new instrument or a novel set of experimental practices that arrives first on the scene. Galileo's telescope, for example, toppled ancient astronomical beliefs while opening up

an entirely new area of astronomy concerned with the description of individual stellar objects, despite the fact that the theory of the telescope remained to be developed. The lesson here is that theoretical investigations were often inspired by technological breakthroughs achieved in the absence of systematic theory. Even when the emergence of a new technology or practice did not precede and thereby stimulate the production of new theory, it was often inextricably intertwined with theory, so that it is misleading to suggest that the branches of sciences that we conventionally label “applied” are applications of preexisting theory to practice. The only safe conclusion, in light of this rich body of historical scholarship, is that undoubtedly the best history of science would be a history of all the sciences, applied as well as pure.

For the purposes of these volumes, however, we decided to set aside those branches of science that on the traditional view would be regarded as applied. It was a case of practical considerations outweighing our goal of comprehensiveness. If we were to include medicine, for example, on the grounds that medicine is a science, we felt that we would then have to include agriculture, preservation of foodstuffs, textiles, and many other practical uses of scientific knowledge. Indeed, we felt that these volumes would have to take account of virtually every material practice of humanity, resulting in a work ten times the size desired.

Although we were forced to exclude areas of scientific study that we would otherwise have wished to include, we were satisfied that the articles were sufficiently comprehensive to give the reader an appreciation of the diversity and richness of scientific practice. The various articles make it clear that history of science is both difficult and challenging as a field of study, requiring expert knowledge in more than one discipline as well as facility with more than one (and sometimes many) language(s).

Although designed with a youthful audience in mind, it is our belief that *History of Modern Science and Mathematics* reflects not only the best existing scholarship but that these volumes often go beyond this in many places and constitute scholarship where none existed previously. The history of twentieth-century chemistry has yet to be written, so the lengthy section on twentieth-century chemistry offered here is a pioneer study of its kind. Even in areas where historical scholarship is rich, these articles often cover new ground, or at least till this ground in new and interesting ways. Again using our treatment of chemistry as an example, the history of chemistry to the eighteenth century included here is a valuable addition to the literature on the subject, particularly for its treatment of Arabic sources of chemical knowledge in the West.

The set, as mentioned above, opens with four topical essays that explore questions about the rationale and scope of the project as a whole. First, there is the question of the method of historical inquiry adopted by the authors of the articles. As committed as we were to the belief that these volumes should leave the reader with an informed and critical awareness of mathematics and the sciences of nature, we also believed that these volumes should instill in the reader the same critical and informed attitude toward the history of these disciplines. The opening article on the relationship between science and the history of science historically situates the approach adopted by virtually all the contributors to these volumes, while serving notice that there are other ways of conceiving the relationship between science and its historical development. The question of the relationship between science and technology is covered in the second topical essay. One of the dominant themes of many of the articles, especially in physics and chemistry, is that the sciences of nature have been increasingly dominated by technology. The second article is a reminder that technology has its own history, apart from its collaboration with science, and it helps to clarify why the history of technology is not treated in a systematic way in this set. Next, the question of the history of medicine and its many rich and deep ties with the natural

sciences is explored in the third topical essay. Although we elected to set aside those sciences that traditionally would have been called “applied,” this essay constitutes something of an exception since it is basically an overview of medical history. We felt, however, that a set such as this would be incomplete without some systematic treatment of the history of medicine insofar as it could trace the field’s scientific underpinnings; this approach had the added appeal of enriching the individual articles on biological fields. Finally, there is the question of the relationship between science and mathematics explored in the fourth topical essay. Although we were committed to the idea that mathematics deserves to be studied in its own right historically, we were also sensitive to the fact that there would be overlap between the mathematics articles and the articles dedicated to the sciences of nature. We therefore elected to include a topical essay on a theme—the nature of mathematical proof—that would help to unify the mathematics articles and set them apart from the others.

Following these topical essays, the reader is presented with three overview articles on the main areas of inquiry featured in these volumes: the biological sciences, the physical sciences, and mathematics. The authors were asked to address in a general and nontechnical way some of the dominant themes in these main subject areas and, where possible, to explore the role played by philosophical and other cultural factors in the development of these areas. The articles on the disciplines themselves follow these overviews. Interspersed throughout these articles are special features, many exploring themes that recur in various articles. These special features were incorporated so that contributors could explore in some detail some of the nuances that were important to the development of scientific knowledge but were in danger of being set aside on the grounds that discussion might disturb the flow of historical narrative. Topics for sidebars included, but were not restricted to, scientific instruments and instrumentation, biographies of scientists, institutions, connections with social and intellectual matters related to science, and connections with other sciences.

The articles, by necessity, vary in technical difficulty. Some of the history of mathematics articles—algebra and calculus, for example—presume a preexisting knowledge of difficult concepts and terminology in these fields, as is also true in other more difficult fields, such as the history of atomic and nuclear science. Readers without a background in the relevant fields may find these articles daunting. These difficulties are aggravated by the fact that scientific concepts and principles undergo revision over the course of time. Occasionally, these revisions are so global and extraordinary in their character that it appears as though the new ideas and practices are utterly removed from old ideas and practices. These revolutionary episodes can be so breathtaking that they often involve a complete reorganization of related fields and implicate fields that were thought to be removed completely from the center of revolutionary upheaval. For instance, the concepts and principles of the classical mechanics associated with Isaac Newton and his legions of followers are no longer viewed as fundamental descriptions of nature; they are nevertheless seen by scientists as useful approximations to more modern values deriving from the new physics that arose in the twentieth century. It is for this reason that students who lack some exposure to classical methods may experience difficulty with some sections of the physics articles. To lessen this type of burden, we have sought to aid the less initiated reader with a series of definitions and cross-references placed in the margins that will help the reader build a fuller and clearer understanding of some of the terms discussed. In-text cross-referencing is also used in instances where a general concept is explored in detail in another article.

A large number of original drawings, as well as illustrations from historical source material, were incorporated to clarify difficult concepts and to help the reader visualize complicated theories and experimental practices. These illustrations often serve as

important reminders that science is a complex activity that calls for the collaboration of a number of intellectual and material resources, including resources that allow scientists to visualize phenomena that otherwise would lie beyond the realm of perception. Indeed, some of the historical illustrations incorporated into these volumes were so central to the growth of scientific knowledge that they served as sources of information independent of associated text.

A cross-disciplinary chronology is included as an appendix and is meant to offer the user an additional research tool. Due to space constraints, all the events, trends, discoveries, and inventions detailed in the articles could not be recapitulated here. Nevertheless, it does present comprehensively all the important highlights covered in the articles—and then some; the researcher can, therefore, consult it independent of the articles for quick and easy chronological research. We presented the material horizontally across a general range of disciplines, so that the user could get a sense of the cross-fertilization of ideas that was so important in the history of science and mathematics.

A name index and subject index complete the set. The name index, which is comprised of all the scientists, mathematicians, and philosophers mentioned in the four volumes, presents the individuals in alphabetical order with life spans in parentheses. The general index includes all subjects, concepts, and topics of research and discovery, as well as related trends, events, institutions, and works of note.

Many people are to be thanked for helping us bring this project to completion. First and foremost, I want to thank the authors of the individual articles, who have taken valuable time away from their teaching duties and research in the interest of contributing articles to this set. These individuals were judged to be the best equipped to give an authoritative account of the historical development of their respective fields. All authors, to my knowledge, accepted this task because they cared deeply about the sort of history that was to be digested by the young audience that would make up the bulk of the readership of these volumes. To this end, the authors were unstinting in their willingness to make changes in their articles in the name of clarity. It was decided that the technically demanding nature of mathematics and the sciences of nature would not be compromised to facilitate an easy and necessarily compromised understanding. Instead, where the content of the science presumed a scientific and mathematical fluency that it would be impossible for our average reader to possess, the authors were asked to return to their desks to clarify the meanings of problematic concepts and, where appropriate, to expand their accounts.

I also want to express my gratitude to my associate editors: Craig Fraser took responsibility for mathematics and helped out in physics, Trevor Levere for chemistry and oceanography, and Polly Winsor for the life sciences and the social sciences. I saw to physics and pitched in here and there. Although I was wildly enthusiastic about this project when first contacted about the prospect of presiding over it, my acceptance was conditional on securing the participation of associate editors with a commanding view of the main topic areas (physics, chemistry, biology, and mathematics) and the international stature that would be needed if the project were to attract the involvement of historians with the right sort of expertise in the subject fields treated in these volumes. The fact that the editorial team was all housed at the Institute for History and Philosophy of Science (part of the University of Toronto) was a bonus, since close proximity made for effortless communication, but I can think of no better partners in an endeavor of this sort, academic affiliation notwithstanding.

A number of people were involved in putting together the illustrations and marginal definitions. Hanna Ezzat, Valerie Tomaselli, Trevor Levere, Mary P. Winsor,

Craig Fraser, Sean Pidgeon, and the contributors all had a hand in the marginal definitions, although responsibility for any errors is ultimately my own. Richard Garratt is to be thanked for original illustrations. For work on tracking down historical illustrations, I would like to thank Sonja Matanovic and my tireless research assistant, Freda Gough, the staff at The Fisher Rare Book Room (University of Toronto), and The Royal Ontario Museum.

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